EE351 Laboratory Exercise 5
Multistage Amplifiers

July 1, 2015

The purpose of this laboratory exercise is to gain experience working with multistage amplifiers with feedback. The amplifier used in this experiment is an introduction to a class of multistage amplifiers known as operational amplifiers.

1.0 Simple operational amplifier (op-amp). This is the generic amplifier whose symbol is shown to the right as used in subsequent steps. The analysis of this amplifier is in the class notes for op-amps. Be sure to study and understand that analysis. The purpose of C1 (if needed) is to limit the high frequency response so that the circuit is unconditionally stable for students. Depending on the particular transistors used and the physical layout of the construction, C1 may not be needed. Use C1 only as needed if your circuit oscillates at some high frequency.

1.1 Build the circuit in Figure 1. Take care to accurately build the circuit as wiring errors will cause major malfunctions and possible destruction of the transistors. Use VCC = +15 volts, VEE = -15 volts, R1 = 100K, R2 = 10K, R3 = 62K, R4 = 3.6K, C1 = 220 pF – initially do not install this capacitor – only use if the circuit oscillates (can use any value between 100 and 1,000 pF if 220 pF not available), NPN transistors are 2N3904, PNP transistors are 2N3906, D1 is 1N4148.

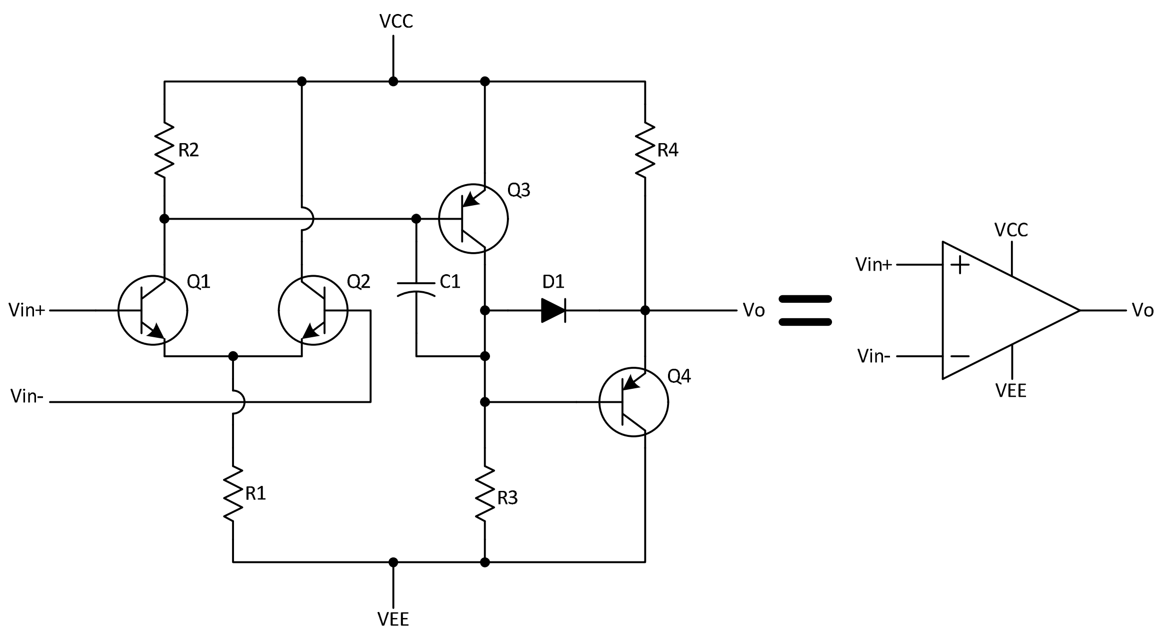

Figure 1: Simple operational amplifier

1.2 Connect the circuit in Figure 2, apply power, and confirm that the output voltage is less than 0.1 volts in magnitude (could be positive or negative). There is a major error in the circuit if the voltage is greater. Do not continue until the problem is resolved as any data taken on a non-working circuit is meaningless. The purpose of the capacitors in the circuit is to minimize the likelihood of the amplifier oscillation when the voltmeter is connected in various ways.

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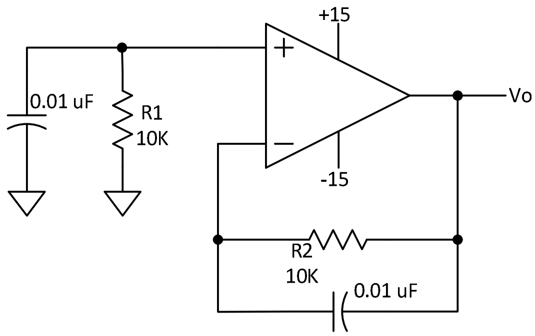

Figure 2: Op-amp test circuit

1.3 **Measuring IB+**. Measure and record the voltage across R1 (should be around -10 mV or less – ~3 mV is typical). Compute the bias current into the into the non-inverting input – that current is through R1 – by definition bias current is positive for current entering the input so the bias current will be the negative of the voltage you measure divided by R1. Report this value as IB+.

1.4 **Measuring IB-**. Measure and record the voltage across R2 (should be around -10 mV or less – ~3 mV is typical). Determine IB- similarly as in 1.3.

1.5 The bias current, IB, for the amplifier is defined as the average of IB+ and IB-. The offset bias current, IBos, is defined as the difference, IB+ - IB-. Compute IB and IBos for your amplifier. Ideally, IB is a very small current and IBos is zero.

1.6 **Measuring the offset voltage, Vos**. Measure and record the voltage between the inverting input and the non-inverting input. This is the offset voltage of the amplifier and generally should not be much more than about 20 mV in magnitude although smaller values are more typical. Ideally, Vos is zero.

2.0 **Demonstration non-inverting amplifier**. Although the internal details of the op-amp are complicated, it is very simple to use the circuit to build an amplifier with very accurately known gain. For the circuit in Figure 3 the voltage gain is 1 + R2/R1 = 101 with the components specified.

2.1 Connect the circuit in Figure 3 with R1 = 1K, R2 = 100K and Vin is a 0.1 Vpp sine wave at 1 kHz.

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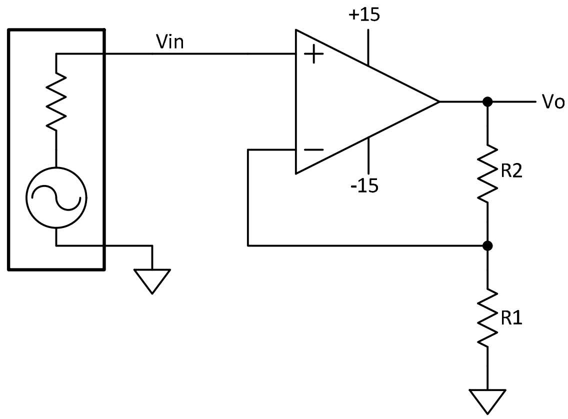

Figure 3: Non-inverting amplifier

2.2 Apply power and the signal source and confirm that the waveform on the oscilloscope is a sine wave without visible distortion and is approximately 10 volts peak-peak. If the output waveform is distorted then something is wrong – fix the problem before continuing. Accurately measure the output voltage and compute the actual closed-loop voltage gain – should be near 100.

2.3 Measuring the output resistance of the amplifier. Connect a 4.7K load resistor from the output of the amplifier to ground. Measure the loaded output voltage (should be undistorted and very similar to the unloaded case in 2.1 – you may have difficulty (it may be impossible – that is actually good) perceiving much difference between the unloaded and loaded case.). Calculate the output resistance, Ro, of the amplifier from your measurements (hint: think of a voltage divider with the output resistance as the upper resistor and the load resistor as the lower resistor. You measured the applied voltage as the unloaded voltage in 2.1 and you measured the loaded voltage in 2.2. The only unknown is Ro.). Expect Ro to compute to be very small – from about zero up to several tens of ohms. Very low output resistance is a desirable result of a high gain amplifier with negative feedback.

3.0 Measuring the open-loop gain, Av. It is a challenge for students to directly measure the high open-loop gain of the op-amp. A better method is to measure as accurately as possible the actual closed-loop gain with the theoretical gain set high enough so that the error caused by finite open-loop gain is readily measurable and then use math to compute the open-loop gain.

3.1 Use the circuit in Figure 5 but use R1 = 100 ohms (accurately measure and record its actual resistance), R2 = 47K (accurately measure and record its actual resistance), and set Vin = 0.02 Vpp sine wave at 100 Hz. Set that voltage as accurately as possible using the oscilloscope – put a 47 ohm resistor to ground across the output of the signal generator if necessary to obtain the low output needed. The output, Vo, of the amplifier should be an undistorted sine wave approximately 8 Vpp. If not then determine what is wrong and make corrections before continuing.

3.2 Accurately measure the output peak-peak voltage and compute the gain of the amplifier circuit (you should compute something around 400 or a little larger – call this $Gain_{actual}$. Note that the theoretical gain with a very high Av is

$$Gain_{theoretical} = 1 + \frac{R_2}{R_1}$$

Solve the following equation to determine the approximate value of open-loop gain, Av, for your amplifier. You should compute Av around 3,500 give or take perhaps a factor of 2.

$$Gain_{actual} = \frac{Gain_{theoretical}}{\frac{Gain_{theoretial}}{Av} + 1}$$

4.0 Precision half-wave rectifier. By incorporating the diode in the feedback loop of the op-amp the rectification non-linearity for small signals is reduced by the gain of the amplifier thus enabling small signals to be accurately rectified. In the circuit in Figure 4, the diode, D2 is used as the rectifier and D1 provides a path for current when D2 is reversed biased. Observe that the node at the inverting input of the op-amp remains at zero volts for either polarity of Vin – any difference from zero is highly amplified and fed back through either the D1 or D2 paths to force the inverting input towards zero.

4.1 Build the circuit in Figure 4 using R1 = R2 = 10K and D1 = D2 = 1N4148. Note that the inverting and inverting terminals are shown in different places than previously – both symbologies are common.

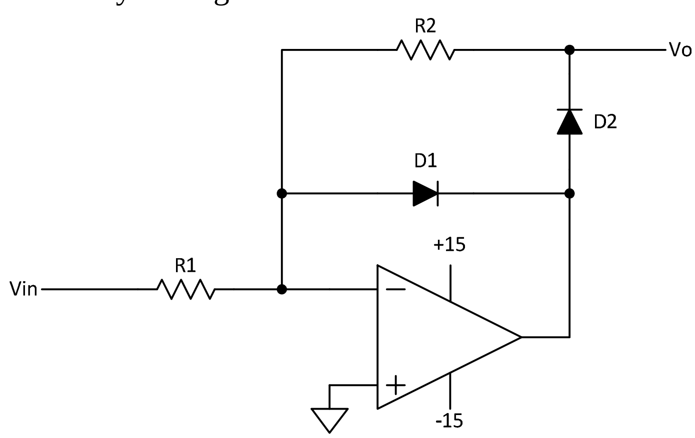

Figure 4: Precision half-wave rectifier

4.2 Apply a 1 volt peak-peak 100 Hz sine wave at Vin and observe that Vo is a near perfect half-wave rectified version of Vin. Fix any problem if that is not the case before continuing.

4.3 Reduce Vin to 0.5, 0.2, 0.1, 0.05, 0.02, 0.01, etc. volts peak-peak and observe the quality of half-wave rectification at Vo. It will gradually loose accuracy as Vin is reduced because of the finite open-loop gain and bandwidth of the amplifier. Determine the smallest value of Vin that in your opinion results in a reasonably accurate half-wave rectified signal at Vo.